VOLTAGE, RESISTANCE AND POWER MEASUREMENTS

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VOLTMETERS

The voltage across any resistance can easily be determined if we know the current through the resistance and the value of the resistance. From Ohm's law, voltage is equal to current multiplied by the value of the resistance. Thus we have a direct method of calculating the potential difference between any two points in a circuit, regardless of the kind of voltage, D.C., or A.C. of any frequency, provided always there is no source of e.m.f. connected within the two points.

From all of this we can derive a very simple method of measuring voltage—that is, by placing a known resistance in series with a calibrated milliammeter, across the voltage difference to be measured.

Fig. 1 shows a supply delivering current to a load. It can be any kind of a supply delivering current to any kind of a load—a motor, a resistance or a resonant circuit. Naturally there is a voltage across the load. Let us say we want to measure it. Its resistance or impedance is not known; therefore an ammeter in series with it would not enable us to compute the voltage. However, by placing between the two terminals whose P.D. is to be measured, a known high resistance in series with a milliammeter, we can obtain sufficient information to compute the P.D. Of course a D.C. milliammeter must be used for D.C. voltages and an A.C. milliammeter for A.C. voltages.

We know that the voltage across the load is the same as the voltage across the resistance R in series with the milliammeter. But we know the value R, and our meter will indicate the value of the current I. The voltage is simply $I \times R$.

A voltmeter is nothing more than an arrangement of this sort. Sometimes you hear a voltmeter referred to as a "potential galvanometer" because all it amounts to is an ammeter used to measure potential differences.

Any milliammeter may be used as a voltmeter, provided the combined resistance of the meter and the external known resistance is high enough to prevent all but a negligible amount of current flowing between the two terminals from being "sidetracked" through the meter. When measuring D.C. potentials, a D'Arsonval type of ammeter is used. When measuring A.C. voltages, an electrodynamic ammeter is usually used, although magnetic vane types of instruments may be used. For audio fre-

quency voltages, a thermocouple or oxide rectifier ammeter is frequently used, while for measuring R.F. voltages a hot wire or thermocouple milliammeter is commonly used. These various types of voltmeters will be discussed separately in the following chapters.

D.C. VOLTMETERS

One of the most important things to remember in connection with voltmeters is that, when a voltmeter is connected across two terminals, the voltage across them is not the same as it was before the voltmeter was connected. A consideration of a resistance load with a definite value of current flowing through it as in Fig. 2 will show why this is true. Let us say the load is a 1,000 ohm resistance and there are 100 milliamperes flowing through it—that is, the meter A indicates .1 amp. The P.D., from Ohm's law, should be $.1 \times 1{,}000$ or 100 volts.

But suppose a voltmeter having a resistance 5,000 ohms

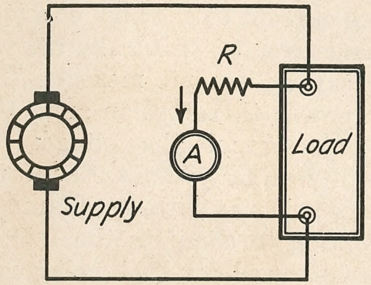

Fig. 1

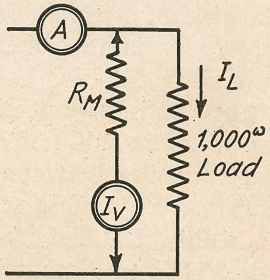

Fig. 2

is connected across this load. What will be the voltage across the load? We are going to assume that the current has not changed—that A still reads .1 amp. This current divides between the voltmeter and the load, 5/6 of it going to the load and 1/6 through the voltmeter. Then $V = 1/6 \times 5{,}000 \times .1 = 83.3$ volts—and our reading is approximately 17 per cent off.

On the other hand, if the voltmeter had a resistance of 100,000 ohms, the part of the total current going through the load would be equal to $100 \div 101$ and the part through the voltmeter would be $1 \div 101$. In this case $V = \frac{1}{101} \times 100{,}000 \times .1$ or 99.1 volts and the error is less than 1 per cent.

Now what does all this mean to us? It means simply that for close voltage measurements, our voltmeter should have an extremely high resistance in comparison to the resistance of the circuit in which the potential difference is being measured.

A voltmeter of the type commonly used by Radio-Tricians for measuring D.C. voltages is shown in Fig. 3a. This is a portable type of voltmeter. The panel type of voltmeter is illustrated in Fig. 3b. Meters of this sort are designed for use in measuring voltage across voltage dividers of power packs and C bias resistors and are designed to have a resistance of 1,000 ohms for every volt on the scale.

You will note in Fig. 3c that the voltmeter has four terminals, one marked minus (–), one +10 volts, one +250 volts and the other +750 volts. The (–) terminal is a common terminal. Thus connecting two points of a circuit whose potential difference is to be measured across this terminal and the +10 terminal, we can read voltages up to 10 volts. Between (–) and +250, we can measure up to 250 volts. And between (–) and 750 we can read up to 750 volts.

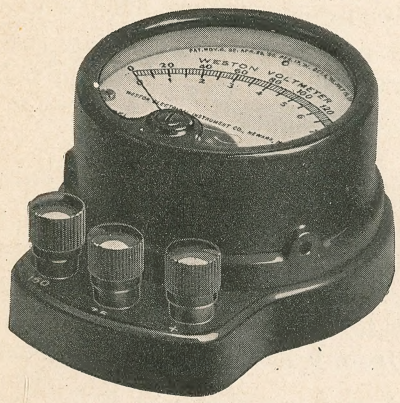
Fig. 3a

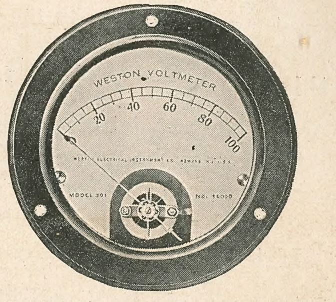

Fig. 3b

When the 0–10 volt scale is used, the voltmeter resistance is $10 \times 1{,}000$ or 10,000 ohms; when the 0 – 250 volt scale is used, the resistance is 250,000 ohms and, for the 750 volt scale, the resistance is 750,000 ohms. For every volt in the range there is a resistance of 1,000 ohms. By using Ohm's law we can immediately see that the meter is a 1 milliampere (.001 amp.) meter, for:

$$.001 \times 250{,}000 = 250 \text{ volts, etc.}$$

The voltages read with a meter of this type would be only 1 per cent off if the resistance of the load across which measurements are taken was 1/100 the resistance of the meter. Therefore, to maintain this degree of accuracy for the various scales, the 0–10 scale should not be used when measuring across loads greater than 100 ohms; the 0–250 range should not be used

when measuring across loads greater than 2,500 ohms and the 0–750 range should not be used on loads greater than 1,500 ohms. Incidentally, a typical, well-made, modern voltmeter is guaranteed to be accurate within 2 per cent when measuring voltages of the order of 100ᵛ—that is, if the meter reads 98 or 102 volts, the meter is as accurate as it is guaranteed to be.

Knowing this, you can easily see why it is not correct to measure the voltages across very high resistances, such as detector resistors, C bias and plate resistors, with a voltmeter of this type.

Anyone can adapt a milliammeter for use as a voltmeter by the use of the proper external resistance.* For best results a 0–1 milliammeter is used, having a resistance between 10 and 15 ohms. Its scale should preferably be divided into 100 divisions. Now suppose we wish to read 0–10 volts. What is the value of the resistance we shall have to use with it?

When placed across 10 volts a current of 1 milliampere must pass through it for full scale deflection. Then the required voltmeter resistance will be calculated from the formula $R = \frac{E}{I}$

In this case $R = \frac{10}{.001}$ or 10,000 ohms. As the meter has only 10 or 15 ohms resistance, this can be overlooked and the external resistance may be made exactly 10,000 ohms. However, should the meter resistance be 500 ohms, it would not be negligible and the external resistance would have to be 9,500 ohms.

If the voltmeter is to read from 0–250 volts, the external resistance would be (neglecting the meter resistance) $R = \frac{250}{.001}$ or 250,000 ohms. If we already have a 10,000 ohm resistor connected to the 10 volt terminal, we can connect a 240,000 ohm resistor in series with this as shown in Fig. 3c (resistor R_{250}.) Then the additional resistor is called a *multiplier*. In Fig. 3c, three multipliers are shown — $R_{10} = 10{,}000$ ohms; $R_{250} = 240{,}000$ ohms, and $R_{750} = 500{,}000$ ohms. All these resistors are standard precision devices. With the use of these multipliers the meter has three scales, a 0–10 scale in which case each main division represents 1 volt, a 0–250 volt scale in which case each main division represents 2.5 volts, and finally a 0–750 scale in which each main division represents 7.5 volts.

It is essential when using multipliers to measure high voltages that the resistance be not concentrated in one bobbin as in

* By the use of the proper shunts and multipliers, a single 0–1 milliammeter can be made to measure various ranges of current and voltage.

Fig. 4, but that it be spread out—and for this purpose several bobbins in series are used. This makes it easier to insulate the resistance wires from each other.

In order to prevent moisture from entering the coils, they are boiled in wax. And to prevent sparking when the terminals of the voltmeter are removed from the circuit under test, the resistances are non-inductively wound. This is accomplished by winding two wires, side by side, from two different spools. The resistance is started by cleaning the insulation from the ends of both wires and soldering them together. Then the correct amount of wire is wound on the form and the two open ends form the terminals of the multiplier. The resistance, of course, is twice the resistance of one length of wire.

Very similar construction methods are used in building resistance units for A.C. voltmeters where extra precautions are taken to prevent distributed capacity.

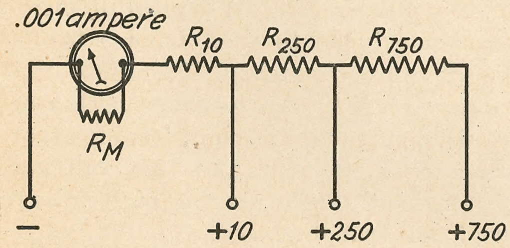

Fig. 3c

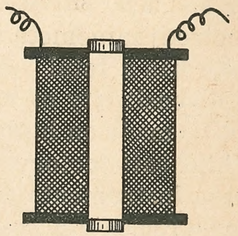
Fig. 4

ELECTRODYNAMOMETER VOLTMETERS (A. C.)

The A.C. voltmeter is basically an A.C. milliammeter. There are several types of A.C. milliammeters that may be used, but the most desirable for accurate measurements is of the electrodynamic type. Here we meet new problems, for the electrodynamic meter has inductance besides resistance and this must be taken into consideration in calculating the series resistance required.

As we learned from an early lesson, when a resistance is placed in series with an inductance, the voltage across the system is equal to:

$$V_M = I_M \times \sqrt{R^2 + (2\pi f L_M)^2}$$

where V_M is the voltage across the arrangement.

I_M is the current through the voltmeter indicated by the milliammeter

L_M is the inductance of the meter
R is the resistance of the voltmeter and the multiplier's resistance (non-inductive)

In the formula the expression $2\pi f L_M$ is the reactance of the milliammeter, and, if it can be made small in comparison with R, we can neglect it. In the design of an A.C. voltmeter, this is always made as small as possible.

An electrodynamometer milliammeter designed to have very little inductance may be connected in series with precision multipliers. However, instruments of this kind are expensive and are not used for ordinary radio work. They are generally used in laboratories and wherever precision is essential.

In radio work for measurement of A.C. power supplies, A.C. voltmeters having comparatively low sensitivity are used. The D.C. permanent magnet voltmeter discussed in the previous chapter has a sensitivity of 1,000 ohms per volt. A typical precision electrodynamometer voltmeter designed to read from 0 to 300 volts has a total resistance of approximately 6,600 ohms—that is, a sensitivity of 22 ohms per volt. And so measurements cannot be made on high resistance loads without considerable error. While satisfactory for measuring filament and line voltages, these instruments are not sufficiently accurate for high voltage measurements across power pack transformers.

Electrodynamometer voltmeters are suitable only for low frequencies—up to about 150 c.p.s. Beyond this frequency the inductance, the resistance, eddy currents and capacity effects in the coils alter the calibration and readings are not reliable.

Fig. 5 shows a typical electrodynamometer voltmeter of the precision type. This instrument is shielded from external magnetic disturbances and the needle is damped. The moving coil system is attached to a fan-shaped aluminum disc which revolves between two permanent magnets. The eddy currents that are induced in it tend to keep the needle deflection steady.

A.C. voltmeters are built to measure up to 750 volts r.m.s. Where higher voltages must be measured, a step-down "potential" transformer is universally used.

MAGNETIC VANE VOLTMETERS

A magnetic vane voltmeter is nothing more than a magnetic vane milliammeter in series with a known resistance. However, the presence of iron in the center of the solenoid affects the inductance of the milliammeter considerably. Therefore instruments of this type are calibrated at known A.C. voltages of a certain frequency and are designed only for use at that frequency. In general, however, it is true that a 60 c.p.s. meter may be used with frequencies from 25 to 130 c.p.s. with little error.

Moving vane voltmeters for high voltage measurements are

FIG. 5

fairly sensitive. A typical A.C. voltmeter of this type commonly used in radio work is shown in Fig. 6. A 0–4 A.C. voltmeter has a sensitivity of 10 ohms per volt; a 0–300 voltmeter has a sensitivity of 166 ohms per volt.

In cases where meters of this type are designed for sensitivity at large voltages, the exciting solenoid is wound with many turns of wire. For very high voltages a step-down transformer is used.

The A.C. voltmeters in most set analyzers are of the magnetic vane type. It should be remembered that they are not intended for use as D.C. voltmeters. Furthermore, they are intended to measure voltages only at commercial power frequencies.

COPPER OXIDE A.C. VOLTMETERS

A copper oxide milliammeter, in series with one or more known resistances, provides a valuable A.C. voltmeter. This type of instrument is used chiefly for measuring A.C. voltages where great sensitivity is desired. It consists of the copper oxide rectifier system arranged in a diamond (bridge) formation, feeding a sensitive D.C. microammeter connected across the bridge. The other two ends of the diamond, in series with a

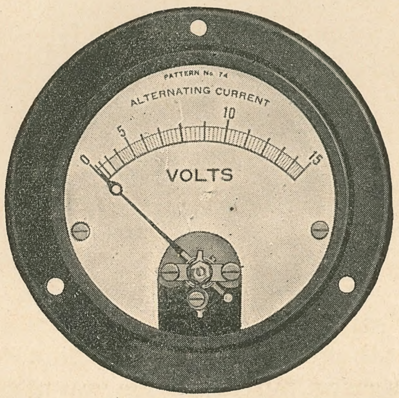

FIG. 6

resistor or resistors, connect across the load whose potential difference is to be measured. A typical arrangement is shown in Fig. 7. With properly chosen multipliers connected as shown, the device would measure voltages from 0–900 in convenient steps.

For ordinary frequencies, 25 to 500 cycles, the impedance of the milliammeter system is negligible and the series resistances merely serve to drop the voltage across the milliammeter bridge arrangement to a given value. As the A.C. current being measured is full-wave rectified as shown in Fig. 8, the D.C. microammeter reads the average value of the half sine wave. Therefore calibration should be made with the use of pure sine wave generators and not on ordinary A.C. unless it is known to have a sine wave. Voltages read with an instrument of this sort are always r.m.s.

Although instruments of this type are very sensitive, they are subject to considerable error. As they are calibrated on pure sine waves, the presence of harmonics in the current being measured will tend to throw the readings off. Then, too, the rectifying property of the copper oxide element decreases with increasing frequency at the rate of 1 per cent for every 2,000 c.p.s. And the rectifier is affected by room temperature. However, if the wave form of the current being measured is a fairly pure

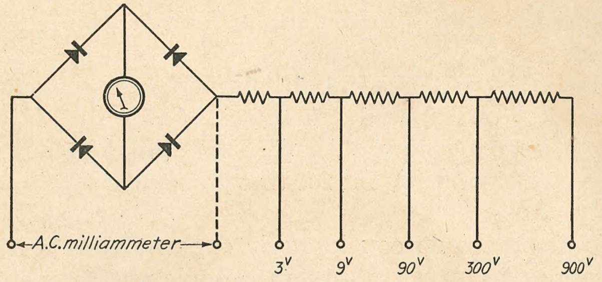

FIG. 7

sine wave, accuracy will be within 5 per cent of full scale reading.

A sensitivity of 1,000 ohms per volt is possible with this type of meter.

By a simple switching arrangement the D.C. meter can be disconnected from the rectifying system and used for D.C. measurements. In this case a different scale will have to be used, or a

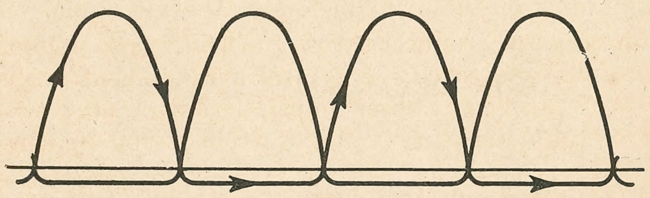

FIG. 8

resistance must be placed in shunt with the meter to compensate for the r.m.s. calibration.

THERMOCOUPLE VOLTMETERS

When it is required to make exact measurements of A.C. voltages at audio or radio frequencies, the thermocouple voltmeter is the best device to use. A voltmeter of this type is simply a thermocouple milliammeter in series with a non-inductive, non-

capacitive resistance which limits the current flow through the meter to a value sufficient to provide full scale deflection.

For R.F. and A.F. measurements, a thermocouple milliammeter is generally used without any multipliers and the voltage is measured in the following manner: The meter is placed in series with the resistance load across which the voltage drop is to be measured—the value of the resistance must be known. By multiplying the value of current flowing by the resistance of the load, the voltage can be determined. If the square of the current measured is multiplied by the resistance, the power output is obtained.

The meter is calibrated in milliamperes for convenience and voltages must be calculated. A meter of this sort is especially useful for measuring hum output or the signal output of power audio tubes. The connections for this purpose would be as shown in Fig. 9.

Radio men who do considerable experimental work usually find it advisable to invest in a thermocouple milliammeter having a range of 0–120. There are available several instruments of this type that are accurate to within 2 per cent on all frequencies ranging from commercial A.C. to radio frequencies. The resistance of these instruments is around 5 ohms. Then an r.m.s. voltage of .6 volt (.120 + 5 = .6 volt) will give full scale deflection.

For exact laboratory work where R.F. voltages of the order of a few millivolts must be measured, microammeters must be used. Fortunately, suitable microammeters are available, and these, too, work on the principle of the thermocouple.

HIGH VOLTAGE MEASUREMENTS

Where potentials of 2,000 volts and more are to be measured, it is general practice to use capacity (electrostatic) voltmeters.

Although voltages this high are seldom used in ordinary radio work, it is well worth understanding the underlying principles of the devices used to measure them.

As you know, when a condenser is charged, one plate is positive and the other is negative. You also know that opposite charges attract. And here you have the principle of the electrostatic voltmeter, as illustrated in Fig. 10.

The force existing between the two plates, one fixed, the other movable and attached to the indicating needle, depends on the voltage and the capacity of the attracting system.

Voltmeters of this type are calibrated by means of voltages whose r.m.s. values are known.

In Fig. 10, terminals T_1 and T_2 are for low range readings. The multipliers used to extend the range are condensers. For each multiplier a separate calibration is necessary.

One big advantage capacity voltmeters have is that they

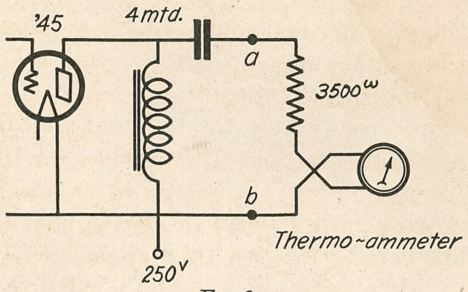

Fig. 9

require little or no current after the initial deflection and they eliminate the necessity for step-down potential transformers. They may be used for A.C. or D.C. measurements over wide frequency ranges.

It might be mentioned that extremely delicate capacity voltmeters for low voltage work have been built, but their use is confined to laboratory work.

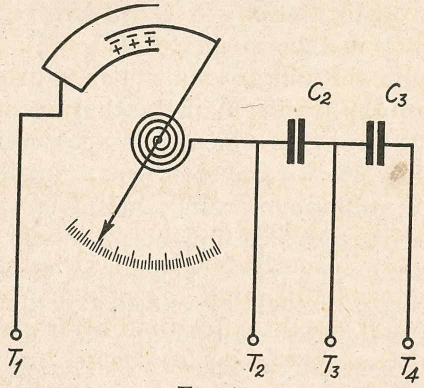

Fig. 10

Another device for the measuring of extremely high voltages, of the order of 10,000 to 200,000 volts (10 to 200 kilovolts), makes use of a spark gap. For voltages from 50 kv. to 200 kv. the spark gap consists of two spherical brass electrodes. The distance between the spark gap at the break-down point can be measured and the voltage determined from a calibration curve.

Then corrections for certain weather conditions, temperature, and humidity should be made for closer results.

Devices of this sort fill a practical need in the making of insulation tests. Extremely high voltages are required—higher than can be measured by the ordinary voltmeter. In practice the gap is adjusted so that it will break down at a certain high voltage. Then the voltage is stepped up by means of transformers until the gap breaks down, which is then an indication that the voltage is sufficiently high for use in testing insulation and dielectric resistance.

The spark gap breaks down at the peak voltage and not the r.m.s. Remember that the peak voltage is 1.41 times the r.m.s. value.

For voltages between 10 and 50 kv., a spark gap of which the electrodes are two No. 00 sewing needles may be used. When these are 11.9 millimeters apart, the gap will break down when 10 kv. are impressed across it. When break-down occurs with the electrodes 41 millimeters apart, 30 kv. are indicated; and when 118 millimeters apart, 60 kv. are indicated.

HOT WIRE AND OSCILLOGRAPH VOLTMETERS

The universal practice of using non-reactive resistors in series with a milliammeter for voltage measurement applies also to the hot wire milliammeter and the oscillograph milliammeter when used for voltage readings. When the reactance is negligible, the voltage V is always equal to $I_a \times (R_m + r_a)$—that is, the sum of the ammeter and the multiplier resistance multiplied by the current through them. Remember this fundamental rule and you will never have any difficulty in determining the proper type of voltmeter to use for any particular purpose.

The hot wire milliammeter in a voltmeter arrangement is used for the same purposes as the thermocouple voltmeter—for audio and radio frequency measurements. Voltmeters of the hot wire type, however, are much less expensive than thermocouple voltmeters, and for this reason they are used much more extensively in ordinary servicing work.

Voltages can be photographed or actually "seen" by the use of a sensitive oscillograph galvanometer in series with a pure resistance.

Neither the hot wire nor the oscillograph voltmeter requires a more complete discussion here than has been given, for in a previous lesson we studied the hot wire ammeter and the oscillograph galvanometer in detail. Their adaptation for use as voltmeters requires merely that they be connected across the potential difference, in series with a known resistance.

$V = I_a \times (R_m + R_a)$

It should be perfectly clear by this time that most voltmeters and ammeters are current indicating devices; the only difference is that one is calibrated to read in volts, the other in amperes.

VACUUM TUBE VOLTMETERS

One of the most valuable devices for use in radio laboratories and at the service bench is the vacuum tube voltmeter, often called the "thermionic" voltmeter. It is as important a piece of equipment as the thermocouple milliammeter.

The great advantage of the vacuum tube voltmeter is that it draws negligible current from the circuit in which a potential difference is being measured, which makes it especially valuable for measuring voltages in the grid circuits of R.F. amplifiers, or voltages across resonant circuits having extremely small current outputs. The ordinary V.T.V.M. (vacuum tube voltmeter) will read A.C. voltages over a range of 0 to 12 volts. On the other hand, voltmeters of this type can be made to read 1 or 2 microvolts, and by the use of shunts they can be used to indicate current values. Just recently announcement was made of the development of a V.T.V.M. that will measure a current flow as small as 60 electrons per second. The sensitivity of this device can be appreciated if we recall that sixteen million, million, million electrons flowing through any cross-section of a wire per second constitute only one ampere of current flow.

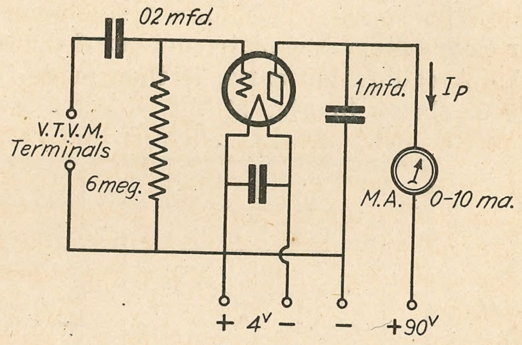

FIG. 11a

Basically the V.T.V.M. is an A.C. detector tube operated with a *C bias* or a *grid leak-grid condenser* control. The grid leak type of V.T.V.M. is the more sensitive—it may be adjusted to read from a few microvolts to 7 or 8 volts.

Fig. 11a shows the schematic diagram of a typical *grid leak-grid condenser* V.T.V.M. In operation the filament is kept at 4 volts in order to prolong the life of the tube. The filament voltage is kept constant by means of a filament ballast or by manual adjustment (a rheostat and a D.C. voltmeter).

The calibration curve for this device is shown in Fig. 11b. While this particular device is not extremely sensitive, it is quite rugged and extremely useful.

A V.T.V.M. is usually calibrated on 60 cycle current by the drop wire method. A toy transformer with a 110 to 10 volt step-down is used to supply the calibrating potential. Across the secondary is connected a low resistance potentiometer. Between the slider contact of the potentiometer and one of the other terminals is connected a 0 to 10 volt r.m.s. 60 cycle voltmeter. See Fig. 12. The V.T.V.M. to be calibrated is connected to the two free terminals. Then by adjustment of the potentiometer arm, the voltage fed to the V.T.V.M. can be changed in known steps, and for each voltage, the plate current of the tube is noted and recorded. A calibration curve is then made from the recorded values as shown in Fig. 11b.

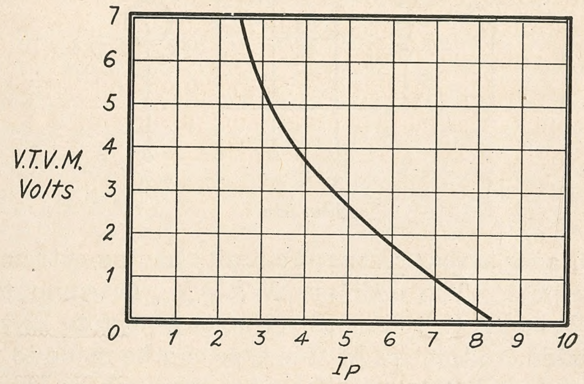

Fig. 11b

Notice the low plate current when high A.C. voltages are measured. The explanation of this is that as the A.C. voltage applied to the grid swings positive, electrons are drawn to the grid. During the negative swing the electrons which have not escaped make the negative swing greater than it would be normally. This causes the plate current to drop and results in a decrease in the average plate current. The grid leak is provided to allow the extra electrons to leak off.

In very sensitive V.T.V.M.'s, microammeters are used to

measure the plate current. In this case it is very important that the D.C. component of the plate current be balanced out so that the microammeter records only current changes. The manner in which this is accomplished is shown schematically in Fig. 13. The meter used is a 0 to 100 microammeter. A shunt should be used in connection with this meter to make it less sensitive until the steady plate current is exactly balanced out.

A 0 to 8 D.C. voltmeter is necessary for checking the fila-

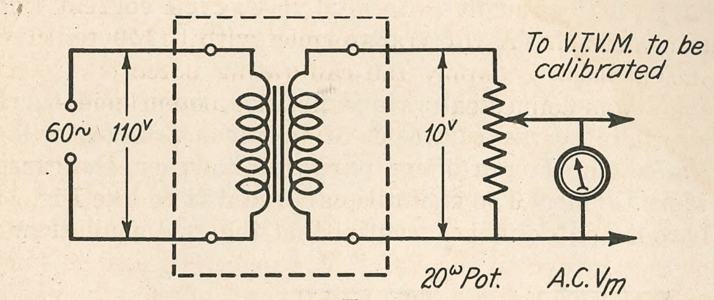

Fig. 12

ment voltage which should be kept always at constant rated value. A 45 volt *B* supply is used, connected to the plate through the microammeter. Between the *B*– and the *A*+ connections there are a variable 10,000ω resistor, a 10,000ω fixed resistor and a 400ω variable resistor. This arrangement supplies a voltage which bucks the plate voltage and provides a means of balancing out part of the D.C. plate current.

The variable resistors are adjusted so that with no A.C.

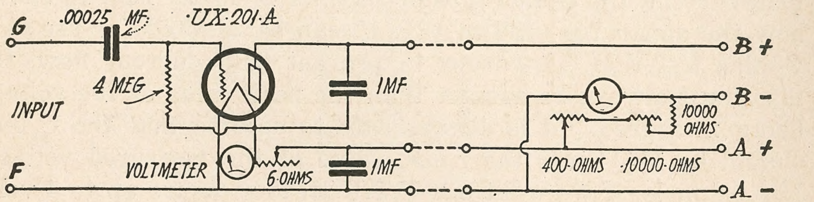

Fig. 13

applied to the input of the device and with the shunt connected across the meter, approximate zero microammeter reading is obtained. Then the shunt is removed from the circuit and the 400ω variable resistor adjusted so that the microammeter reads exactly full scale, in this case 100 μa.*

* If the meter is adjusted originally to zero, actual calibrations and readings should be made with the meter terminals reversed. Otherwise the meter will read off-scale.

After most of the D.C. plate current has been balanced out in this way, the V.T.V.M. is ready for calibration. This should be done by the use of known A.C. voltages. The same arrangement is used as in Fig. 12 except that a fixed drop wire is connected between the vacuum tube voltmeter and the low voltage side of the transformer. Fig. 14 shows the details. Notice the 100 ohm resistor in series with a 900 ohm resistor. Of course the voltage across the smaller resistor will be 1/10 the total voltage—that is, 1/10 of a volt if the total voltage is 1 volt. A 1 ohm resistor in series with a 1,000 ohm resistor will reduce the voltage to .001 volt.

Naturally, as the grid swings positive, some grid current will flow and the measurement of terminal voltages will be slightly affected. For ordinary purposes, however, the current drawn is negligible. The calibration curve will be like Fig. 11b.

Where it is absolutely essential that the grid shall draw no

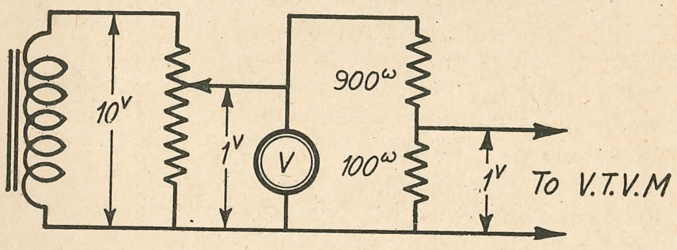

FIG. 14

grid current, the *C bias type* of rectifier is used. Fig. 15 shows how the apparatus used in Fig. 13 can be adapted for use as a C bias V.T.V.M. In order to prevent grid current flow, the bias must always be greater than the peak value of the voltage being measured. It is always safe to assume that the C bias should be 1½ times the r.m.s. value of the measured voltage. For example, if we want our V.T.V.M. to measure up to 4 volts r.m.s., the C bias should be 1.5 $\times$ 4 or 6 volts. In this case the bucking adjustment is made so the meter reads *zero* when no A.C. voltage is applied to the V.T.V.M. The calibration curve will show increased plate current as the applied measured voltage is increased.

Higher voltages may be measured by using larger grid biases and larger plate voltages. The relation of C bias voltage to plate voltage should always be such that the tube operates at the point of greatest curvature of its E_g-I_p characteristic. The

use of less sensitive meters as shown in Fig. 11a will increase the range, using, however, a C bias.

The range of a V.T.V.M. may be extended by using a drop wire as shown in Fig. 16. A 99,000 ohm non-inductive, non-capacitive resistor is placed in series with another resistor of 1,000 ohms. The V.T.V.M. is connected across the 1,000 ohm resistor while the terminals 1 and 2 are connected to the termi-

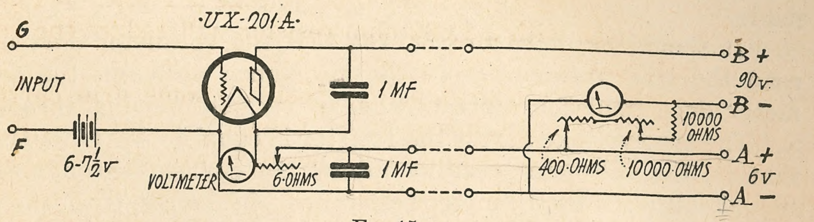

FIG. 15

nals at which the voltage is to be measured. If the V.T.V.M. normally reads up to 10 volts, with the drop wire the range will be extended 100 times (100,000 ÷ 1,000) ; that is, it will now read up to 1,000 volts.

The V.T.V.M. can also be used to measure current if the grid input of the voltmeter is shunted by an R.F. shunt re-

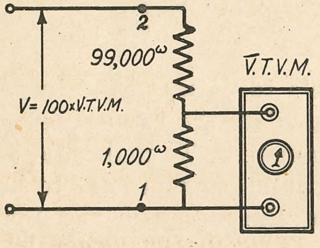

FIG. 16

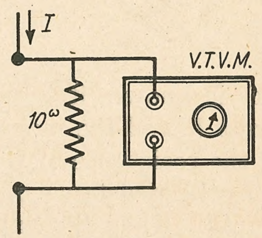

FIG. 17

sistance. If a .01 volt grid leak V.T.V.M. is shunted by a 10 ohm resistor, the maximum current that can be read will be .001 ampere ($I = \frac{.01}{10}$). This is shown in Fig. 17.

If vacuum tube voltmeters are properly by-passed, they can be safely used to measure voltages at either audio or radio frequencies with little error, even though they were originally calibrated at 60 cycles.

MEASURING RESISTANCE

If a voltage of known value is connected across a resistor whose value is not known, and the current through the resistance is measured, the resistance in ohms can be calculated from Ohm's law. See Fig. 18a for the set-up. A D.C. supply is used, and the meters are also D.C. instruments. It is not essential that the voltmeter have a very high resistance or that the ammeter have a very low resistance if the proper corrections are made.

It should be noted in Fig. 18a that the voltmeter does not read the true voltage across the resistance although the ammeter does read the correct value of current flowing through it. The true voltage across the resistor is equal to $V - (I \times R_1)$; that is, the voltmeter reading minus the current through the meter multiplied by the meter resistance. Of course, if the meter

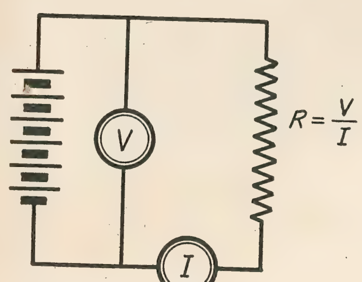

FIG. 18a

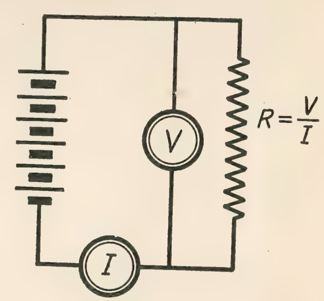

FIG. 18b

resistance is known, it is possible to measure the total voltage drop across R and the meter, calculate the total resistance, and subtract the resistance of the ammeter. To make the necessary corrections the resistance of the ammeter will have to be known or measured. Then the value of the unknown resistor will be the total resistance, calculated from the voltmeter reading, minus the ammeter resistance.

An alternate method of measuring resistance is shown in Fig. 18b, where the voltmeter is connected directly across the unknown resistance and the ammeter is placed next to the voltage supply. In this case the voltage reading will be the true voltage across the resistor, but the ammeter will not read the true current through the unknown resistor for the voltmeter is in parallel with it. That is, the ammeter will read the current through the resistor plus the current through the voltmeter. To find the true current, subtract the voltage reading divided by the voltmeter resistance from the ammeter reading. In other words, the true $I = I_{AM} - \frac{V}{R_{VM}}$.

Most voltmeters have a resistance of from 200 to 1,000 ohms per volt. If you are using the 10 volt scale of a 200 ohm per volt meter, the voltmeter resistance will be this factor multiplied by 10—in the case mentioned, 200×10 or 2,000 ohms.

The resistance is always the true voltage across the resistor divided by the true current through it.

In Fig. 18a, if a low resistance ammeter is used, the error is negligible and correction is not necessary. In Fig. 18b, if a high resistance voltmeter is used, the error will be negligible and correction unnecessary. When both low resistance ammeters and high resistance voltmeters are used, either connection 18a or 18b may be used and corrections are unnecessary.

For measurement of widely varying values of resistance,

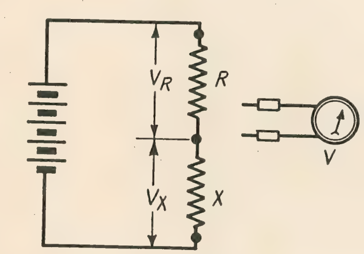

FIG. 19a

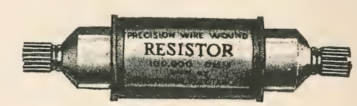

FIG. 19b

multi-range meters are necessary. In this case, the range which permits ¾ to full-scale deflection should be used.

Fig. 19a illustrates what is known as the double voltmeter reading method of measuring resistances. A single high grade multi-range 1,000 ohm per volt voltmeter is used in conjunction with precision resistors of various values—1, 10, 100, 1,000, etc., ohms. The known resistor R and the unknown resistor X are connected in series across the voltage supply. Voltmeter readings are taken across both resistors. Let these readings be represented by V_R and V_X. Then the value of the unknown resistor is:

$$X = R \times \frac{V_X}{V_R}$$

For exact measurement, R should be chosen as near the value of X as possible—that is, V_X and V_R should be approximately equal.

A typical precision resistor, of the type commonly used by service men when measuring resistors by this method, is shown in Fig. 19b.

Often in practical work it is sufficient to determine only the approximate values of resistances. For example, at the service work bench it is not often necessary to be able to measure resistances exactly, but a means of making rapid measurement is desirable. For this purpose ohmmeters are used. As shown in Fig. 20, an ohmmeter is simply a milliammeter calibrated to read directly in ohms. Incidentally, any milliammeter can be used as an ohmmeter by means of a calibration curve made by plotting meter readings against known values of resistances.

The ohmmeter shown in Fig. 20 consists of a 0–1.0 milliammeter of the D'Arsonval type in series with a 3 volt source of e.m.f. (usually a flash-light battery) and a 4,000 ohm rheostat. Two test prods are included.

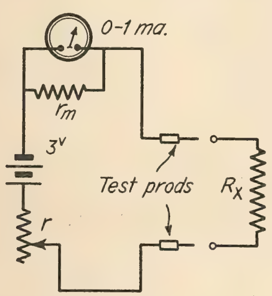

FIG. 20

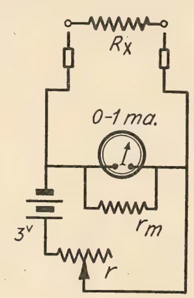

FIG. 21

When the test prods are held together, the meter, the variable resistor and the 3 volt battery are all in series. With the variable resistor adjusted for 1 mil. of current flow, assuming the battery voltage is exactly 3 volts, the combined resistance of the circuit, including that of the resistor, the meter and the battery, will be $3 \div .001$ or 3,000 ohms. Now when the prods are connected across a resistor to be measured, the current that flows will be equal to $3 \div (3{,}000 + R_X)$. and as we are interested in computing the resistance R_X, we may arrange this in formula form:

$$R_X = \frac{3}{I} - 3{,}000$$

For example, if I is .8 mil. (.0008 amp.), a 750 ohm resistor is indicated. If I is .5 mil. (.0005 amp.), 3,000 ohms are

indicated. If .2 mils. (.0002 amp.), 3,000 ohms; .1 mil., 12,000 ohms, etc. With this information we can plot a calibration curve or the scale of the meter may be calibrated directly in ohms.

Because of the circuit arrangement, the ohmmeter in Fig. 20 is called a series type ohmmeter. It is an ideal ohmmeter for measuring large resistances.

For measuring low resistances rapidly and with a fair degree of accuracy, a shunt type of ohmmeter, shown schematically in Fig. 21, is used. The meter used is a milliammeter.

Assuming that a 0–1 milliameter is used, when the prods are separated the resistor r should be so adjusted that 1 mil. of current flows and the meter needle deflects full scale. As r will

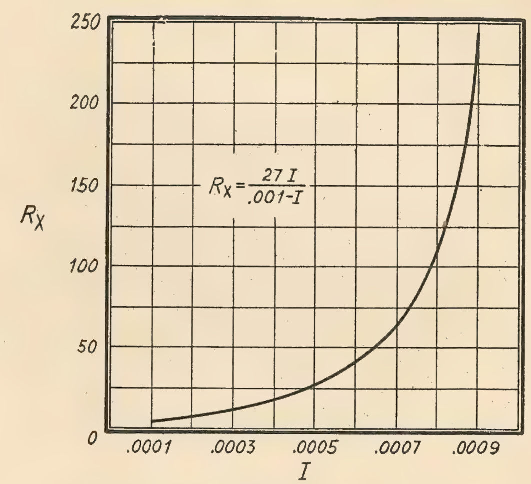

FIG. 22

be about 3,000 ohms and r_m, the meter resistance, will be about 25 ohms, it is evident that the prods can be held together, shorting the meter, without affecting the current flowing in the circuit—it will still be .001 amp.

Knowing this, we can work out the principle of the operation of our shunt-ohmmeter. The voltage across the meter will be $r_m \times I$—that is, the resistance multiplied by the current indicated by the meter. This voltage will also act across the unknown resistor R_X which is connected between the prods of the ohmmeter and will be equal to the resistance R_X multiplied by the current flowing through R_X. Knowing that the main line current is .001 amp., the current through R_X will be .001 less the current through the meter. Therefore its voltage is (.001–

$I) \times R_x$, and this is, of course, equal to $I \times r_m$. From this we develop the formula:

$$R_x = \frac{r_m \times I}{.001 - I}.$$

A calibration curve for an ohmmeter using a Weston type 301 0-1 ma. panel milliammeter which has a resistance of 27 ohms, is given in Fig. 22.

MEGGERS

The name "megger" is simply a contraction of "megohm meter." Thus meggers are devices for measuring resistances in terms of megohms—that is, extremely high resistances such as leakage resistances and resistances of insulating material.

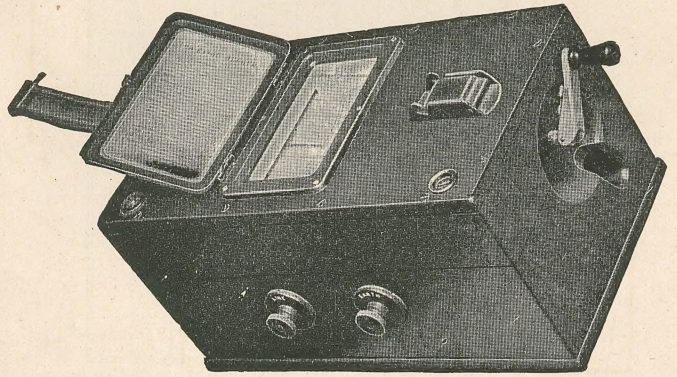

FIG. 23

These measurements are often extremely valuable as in the case of paper condensers, in which the measurement of the leakage resistance is an indication of the useful life of the condenser. The windings of power chokes must be well insulated from the iron cores. In transformers the primaries must be well insulated from the secondaries. The leakage resistance of an insulating bushing on a variable condenser is an indication of the efficiency of the support.

The "megger" insulation testing and high resistance measuring instrument shown in Fig. 23 consists essentially of a special direct reading ohmmeter of the permanent magnet-moving coil type, mounted in a suitable case along with a hand driven generator.

The diagram in Fig. 24 shows details of the magnetic circuit and electrical connections. *M* represents permanent bar magnets. Between the poles at one end is the armature *D* of the hand-driven generator, and between the poles at the other end is the moving system of the ohmmeter.

There are three coils, *A*, *B* and *B′* (in Figs. 24 and 25), fastened rigidly together. The assembly is free to rotate about the axis. There are no controlling springs, but current is led to the coils by flexible copper leads having the least

possible torsion, so that the pointer "floats" over the scale when the generator is not in operation.

Coils *B* and *B′* are connected in series with resistance *R* across the generator potentials. They constitute the "control" element of the ohmmeter and give the instrument the property of indicating correctly, regardless of the exact value of the generator potential or the strength of the permanent magnet. These coils are so connected that when a potential is applied they tend to turn the axis in a counter-clockwise direction until they assume a position where their rate of cutting the magnetic flux is zero—that is, directly opposite the gap in the *C*-shaped iron core about which *B′* moves. The pointer then indicates infinity on the scale. This is the reading obtained when a megger is operated with nothing connected across the terminals marked *earth* and *line*.

The moving coil *A*, which for the most part is in a uniform electromagnetic field, is in series with the generator, the ballast resistor *R′* and the unknown resistance which is connected to the terminals earth and line. The electrical connections are such that this current tends to turn the axis in a clockwise direction, in opposition to that of *B* and *B′*. When the earth and line terminals are

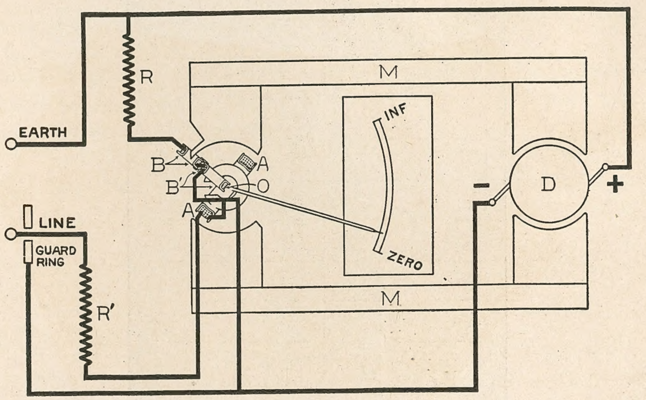

FIG. 24

short circuited, the current produced by *A* overpowers that of *B* and *B′* and the pointer stands over the point marked zero.

Now if a high resistance is connected across the external terminals, the current from the generator has two paths over which it can flow. Therefore it divides, part passing through the control coils *B* and *B′*, and part through coil *A* in series with the resistance under test. The result is that the opposing currents of the two elements balance one another at a point on the scale corresponding to the value of the resistance under test. In this way, also, by using known values of resistance, the scale can be calibrated.

The ordinary megger operates at a voltage of 500^v, which is kept fairly constant even though it is supplied by a hand driven generator, by means of a special control. When necessary, the voltage supply to the device under test may be reduced by increasing the resistance of *R′* (by means of a rotary switch). However, with each change of *R′*, the scale readings change. For simplicity, these scales are usually arranged so that readings are 1/10 and 1/100 of the original scale values. A typical megger reads from 2 to 1,000 megohms with alternate scales from .2 to 100 ohms or 20,000 ohms to 10 megohms.

There is on the market a small portable megger which has been proven highly useful in the installation of centralized radio systems, sound recording and amplifying systems, public address and sound picture equipment. In many cases, proper testing of insulation resistances will mean a saving of considerable time and trouble.

MEASURING POWER

Determination of the power delivered to a load in a D. C. circuit is a comparatively simple matter. All we have to do is to measure the voltage across the load, the current through it, multiply these two values together, and we have the power in watts. Of course the voltmeter used should have a very high resistance as compared with the resistance of the load of which measurements

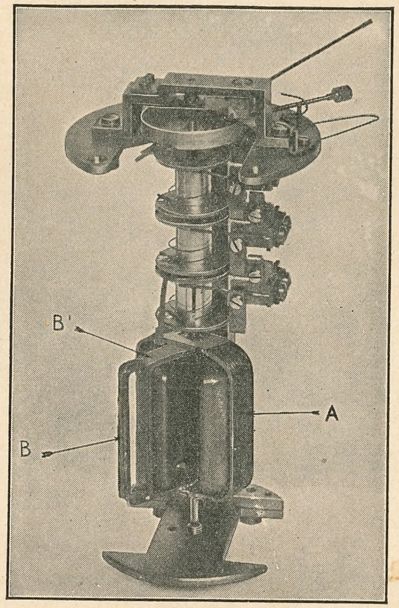

FIG. 25

are taken, and the ammeter must have a very low resistance so that the values read are true values. Thus power in watts is always equal to the true I multiplied by the true V.

In A.C. circuits, however, the determination of power is not so simple. The volts multiplied by the amperes as measured between two terminals do *not* represent the power used by a load or delivered by two terminals because the *power factor* must be taken into consideration. As you know, the power factor corrects for phase conditions.

If you measure the A.C. voltage across a load in an A.C. circuit, and the current through the load, the product of the two ($I \times V$) is the *apparent* power—not in watts but in volt-amperes (V.A.) or kilovolt amperes (KV.A.). For example, if a voltage of 110 was measured and the current was found to be 1.5

amperes, the apparent power delivered to the load or absorbed by the load would be 1.5×110 or 165 volt-amperes (.165 KV.A.).

To find the power in watts, the apparent power must be multiplied by the power factor. That is, $P = V \times I \times$ P.F.

In Fig. 26 the voltage V leads the current I by a certain number of degrees which we call θ. The actual power is $I_E \times VI_E$. I_E, you will observe, is obtained

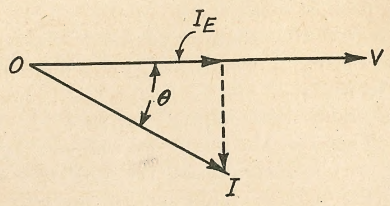

FIG. 26

by drawing a perpendicular line from the end of line I to the line OV. The ratio of I_E to I is the power factor; that is, P.F. $= I_E \div I$.

Unless we know the power factor exactly, to measure the real power we must use a wattmeter, an instrument almost identical in appearance and construction to an electrodynamic ammeter.

Fig. 27 illustrates the working principle of the wattmeter. There are two coils, one within the other. These coils are only inductively coupled. The

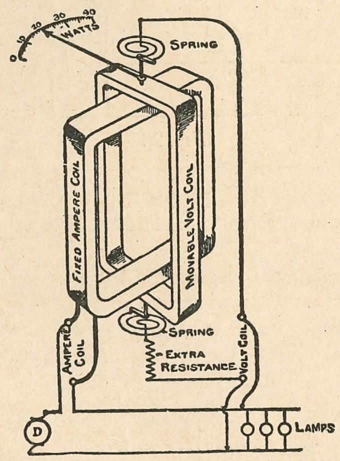

FIG. 27

inner coil is made of very few turns of relatively heavy wire. The outer coil is made of many turns of fine wire and is in series with a high resistance. When a device of this sort is used to measure power delivered to a load, the inner coil is connected in series with the load and its magnetic field will be proportional to the current through the load. The current that flows through the outer coil will be proportional to the voltage of the load and its magnetic field will be proportional to the load voltage.

The two coils are set at right angles to each other. When current flows through them, their magnetic fields interact. The inner coil is free to move and, when the magnetic fields about both coils interact, the inner coil is twisted; that is, it is given a mechanical torque, to a degree depending on the relative intensity of the two fields. The twist is balanced by a coil spring and the deflection of the inner coil is indicated by a pointer moving over a graduated scale.

As the "twist" is proportionate to the product of the magnetic field of one coil and the magnetic field of the other, and as these fields are determined by the voltage across and the current through the load, naturally the amount of the twist indicates power in watts.

The device is so designed that only *effective* current and voltage contribute to the twisting effect. Therefore the wattmeter is a true power indicator. When an instrument of this sort is magnetically shielded and provided with air or magnetic eddy current dampers, it can be used to measure either D. C. or A. C. power up to 150 cycles with little error.

The wattmeter is hand calibrated against known powers. These instruments are obtainable in ranges of a few watts to many kilowatts. Milliwatt meters are also available for the measurement of small powers. Of course any wattmeter must be designed to carry the voltage and the current of all loads to

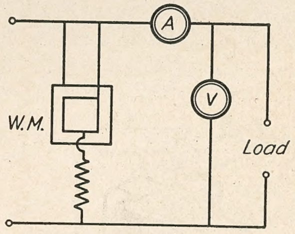

FIG. 28

be measured. For testing the A.C. power delivered to a radio receiver, a wattmeter capable of withstanding a voltage of 150 and capable of carrying 3 amperes maximum current is required.

Sometimes it is necessary to determine the power factor of an A.C. supply. To find the power factor, a set-up as shown in Fig. 28 must be used. There is a wattmeter, an A.C. voltmeter and an ammeter connected as shown. The voltmeter and ammeter will enable us to calculate the apparent power and the wattmeter will tell us the effective power. Then the power factor will be found from the formula:

$$\text{P.F.} = \frac{\text{effective power}}{\text{apparent power}} = \frac{W}{V \times I}$$

OUTPUT INDICATORS

Often in testing at the service work bench or in the laboratory it is necessary to measure the power output of a radio receiver. In the early days of Radio about the only check on the power output was obtained by listening to the output of the loudspeaker. But since then Radio has advanced to become an extremely exact science, and exact methods of measuring the power output were developed.

Along with A.C. receivers came the problem of hum, and in the development of means to reduce the hum output it became necessary to have accurate means of measuring the amount of hum in the receiver output.

In this chapter we are going to see how power output and hum measurements are taken. Let us work with a typical output stage—a pair of '45 type tubes in push-pull. As a loudspeaker is not a constant impedance device, we disconnect it and connect in its place a suitable resistor.

As the total tube impedance is $2 \times 1{,}750$ or 3,500 ohms, a 3,500 ohm resistor connected across the output will result in maximum power output. It is this output we want to measure.

A single 45 tube will deliver a maximum of 1.6 watts of power and two in push-pull deliver about 4.0 watts. The current through the load resistance may be calculated from the formula $P = I^2R$—the power to be wasted as heat. With a maximum output of 4 watts,

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{4.0}{3{,}500}} = .032 \text{ amp., approximately (32 ma.)}$$

From this we can see that a 0 – 50 milliampere thermocouple ammeter in series

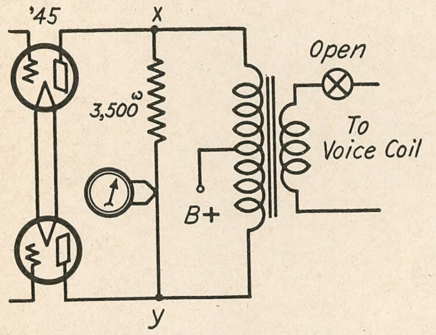

FIG. 29a

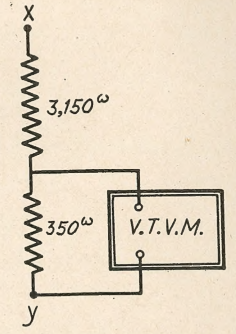

FIG. 29b

with the load resistance or a vacuum tube voltmeter will indicate the current through it and enable us to calculate the actual power output up to the maximum value.

The output voltage is $I \times R$; and the power output will be I^2R. A thermocouple ammeter or a V.T.V.M. should be used as these are the only instruments that can be used with precision on low and high frequencies and in this case the frequencies may be as low as 60 cycles or as high as 10,000 cycles.

When measuring hum output a 0–1 milliampere meter should be used as the amount of hum that should be present is less than .15 volt. When hum measurements are taken, it is absolutely essential that the antenna be disconnected so that no R.F. signals are picked up, otherwise the meter will be burned out.

Thermocouple ammeters are expensive and extremely delicate. For this reason the vacuum tube voltmeter is a more practical device for measuring output powers. Fig. 29b illustrates the use of a V.T.V.M. across the output of two '45 tubes in push-pull. With a V.T.V.M. connected as shown across only 350 ohms of the 3,500 ohm load resistor, the V.T.V.M. will read 1/10 the entire voltage across the resistor. Our vacuum tube voltmeter will be of the type that

will read from 0 to 15 volts, and its readings will have to be multiplied by 10 to give the true voltage.

The power lost in the load will be equal to $E^2 \div R$.

A vacuum tube voltmeter is accurate at any audio or radio frequency.

Often it may be desired to get a rough approximation of the power output with the receiver in operation. In this case a vacuum tube voltmeter can be connected directly across the voice coil of the speaker. A 0–5 volt instrument may be used.

Another simple method involves the use of a fixed carborundum detector in series with a 0–10 milliammeter. When this method is used, a high variable resistance should be connected in series with the meter to prevent the meter needle from flying off scale. A device working on this principle serves only as an output indicator, and measurements are not accurate.

A copper oxide voltmeter may also be used, but here, too, results will not be very accurate, due to the presence of harmonics. A device of this sort used in laboratory testing where single frequencies are measured will be accurate to within 5 per cent.

TEST QUESTIONS

Number Your Answer Sheet 29FR and Add Your *Student Number*.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. How can a milliammeter be used to measure voltage?
2. What type of milliammeter would you use in series with a known resistance in making voltage measurements on the following types of current:
   (a) D.C.
   (b) A.C. 60 cycle.
   (c) A.C. audio frequency.
   (d) A.C. radio frequency.
3. In A.C. measurements what quantity is measured in volt-amperes?
4. What two types of V.T.V.M.'s are there?
5. What type of ohmmeter should be used for measuring low resistances?
6. How can current be measured by a V.T.V.M.?
7. In measuring the voltage across a high resistance load would you use a moving vane meter or oxide rectifier voltmeter? Explain your answer.
8. Suppose you have a 0-10 milliammeter having a resistance of 500 ohms, and you want to use it to read 0-10 volts. What value of multiplier (in ohms) will you use?
9. Show by a diagram how a thermocouple voltmeter is connected for output power and hum voltage measurements.
10. If you had a low resistance voltmeter and a low resistance ammeter, would you use the connection shown in Fig. 18a, or Fig. 18b for making resistance measurements, without the necessity of correction?